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Title

Subgrade Soil Stabilization Practice of AACRA

M.Eng. Independent Project

By

Tsion Argu

School: Civil Engineering and Construction Technology

Department: Civil Engineering

Program: Road and Transport Engineering

Major Advisor:

Co-Advisor:

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Abstract

Subgrade soils are essential components of any pavement structures. The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures. In order to avoid most of the problems that has been appearing on the upper layer of any pavement it is better to treat the subgrade soil. Soil stabilization can be explained as the modification of the soil properties by chemical or mechanical means in order to enhance the engineering quality of the soil. It provides better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength of soil. AACRA uses shallow/surface stabilization it is because shallow/surface stabilization has the advantage over the lime pile technique that it ensures efficient contact between lime and clay mineral particles of the soil. The aim of this project is to assess subgrade soil stabilization practice of AACRA. Hence the objectives of this paper are to identify the benefits of subgrade soil stabilization and to make recommendation.

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Symbols and Abbreviations

AACRA	Addis Ababa City Roads Authority
PI	Plasticity Index
FCR	Fine crushed rock
LL	liquid limit
PH	Potential of Hydrogen
Ca(OH)2	Calcium Hydroxide
CaO	Calcium Oxide (Quicklime)

1. INTRODUCTION

1.1. Background

Soil that are highly susceptible to volume and strength changes can cause severe roughness and accelerate the deterioration of the pavement structure in the form of increased cracking and decreased riding quality in combined with truck traffic. Subgrade soils are an essential component of pavement structures, and poor performance of subgrade soil is the cause of pavement failures.

Pavement performance can be largely attributed to the performance of its foundation or subgrade layer [14]. Therefore, subgrade layers must provide the following:

- Shear strength:- the ability to resist shear stresses developed as a result of traffic loading,
- Modulus (stiffness):- the ability to respond elastically and minimize permanent deformation when subjected to traffic loading,
- Resistance to moisture:- the ability to resist the absorption of water, thus maintaining shear strength and modulus, and decreasing volumetric swell,
- Stability:- the ability to maintain its physical volume and mass when subjected to load or moisture, and
- Durability: - the ability to maintain material and engineering properties when exposed to environmental conditions such as moisture and temperature changes.

Soil stabilization is the treatment of soil so as to improve its engineering properties of the soil. It is the process of creating or improving certain desired properties in a soil material so as to make it stable and useful for a specific purpose. The process may include blending of soils or mixing of commercially available additives these may have the following benefits:-

- It reduces the plasticity characteristics of soil,
- It reduces the swell potential of expansive soil,
- It Lowers permeability of water and even protect soil erosion,

- It eliminate excavation, therefore it avoids exporting unsuitable material and importing a new better quality material respectively,
- It makes compaction process easy,
- It helps to provides all-weather access,
- It reduces the overlaying pavement thickness and
- It improves the strength of soil, by this it prolongs the life of the pavement and extends service maintenance cycles of the roads.

The long-term performance of any construction project depends on the soundness of the subgrade soils. Reactive chemicals either alone or in combination with each other can be used to treat soil. They have the capacity to transforming poor soils into structurally sound construction foundations. The intention of this paper is to assess subgrade soil stabilization practice of Addis Ababa City Roads Authority and make recommendations for the stabilization practice.

1.2. Statement of the Problem

Roads are among the most important public assets in many countries. It charges higher direct and indirect costs. Road improvement brings immediate and sometimes dramatic benefits to road users through improved access and mobility to the most economic resource and market areas. It also improves safety, comfort, speed, and lower vehicles operating cost. To attain these benefits the construction of roads should be on a well and stable subgrade soil. A well and stable subgrade soil results in improved load bearing capacity, life span and maintenance cycle of road and it also lowers permeability of water to the subgrade soil. AACRA is responsible for the construction, administration as well as maintenance of Addis Ababa city roads network. Currently there is huge construction of roads in the city and the road coverage of the city is increasing from time to time, but it is common to see a lot of defects in both the newly constructed roads as well as existing roads that stabilized by lime stabilizer. The aim of this paper is to assess subgrade soil stabilization practice of AACRA.

1.3. Objective

The objectives of this project are as follows:

- To assess the subgrade soil stabilization practice of AACRA.

- To make recommendation.

1.4. Project Question

To achieve its objective the following research questions are proposed:

- Is sub-grade soil stabilization essential?
- Is the stabilization practice of AACRA effective?

1.5. Project Hypothesis

Based on the above project objectives and questions, the following hypothesis is proposed for this paper:

- AACRA subgrade soil stabilization practice is ineffective so that a lot of defects are observed on lime stabilized roads in Addis Ababa.

1.6. Scope and Significant of the Project

The project focuses on subgrade soil stabilization practice of AACRA. In terms of area its scope is limited in Addis Ababa City, by sample roads and only on the stabilization practice of Addis Ababa City Roads Authority. The research has the following significance:

- It will be a feedback for AACRA to improve its stabilization practice.
- It will be a bench for further research in areas of subgrade soil stabilization.

2. LITERATURE REVIEW

Subgrade soil is the supporting ground beneath the pavement upon which pavement rests. It support loads transmitted from pavement structure with deformation being within allowable limits under the action of heavy traffic and adverse climatic conditions. Subgrade soils are an essential component of pavement structures, and inadequate subgrade performance is the cause of many pavement failures.

Subgrade soil's properties significantly influence pavement construction operations and the long-term performance of the pavement. Subgrade soil stability is a function of a soil's strength and its behavior under repeated loading [7]. Therefore, the subgrade soil should be sufficiently stable to:

1. Provide good support for placement and compaction of pavement layers;
2. Limit pavement rebound deflections to acceptable limits; and
3. Prevent the development of excessive permanent deformation (rutting) in the subgrade during the service life of the pavement.

When the subgrade does not possess these qualities, corrective action in the form of a subgrade treatment is needed. Subgrade soil treatment refers to the stabilization of natural soil which makes it more stable.

2.1. Definition of Stabilization

The definition of stabilization varies among agencies. In a physical sense, stabilization consists of a set of mechanisms directed toward extending the life of a pavement in a serviceable state. It includes blending of different soil or addition of chemicals in the soil. The following are some of the definition of stabilization:

- Stabilization is the action of treating something or the state of being stabilized.
- Soil stabilization is the process by which a stabilizing agent is added to the natural soil in order to enhance the engineering quality of soil by mechanical or chemical means or

both. It is a method or technique used to prolong the life of a pavement by slowing down the rate of deterioration.

- Soil stabilization is a procedure where natural or synthesized additives are used to improve the engineering properties of weak soil [15].

In general, soil stabilization is the process of improving certain desired properties in a soil material so as to make it stable and useful for a specific purpose. It is used to increase the bearing capacity of the soil, its resistance to weathering process and soil permeability. The main and only objective of subgrade soil stabilization in this paper is to construct structurally sound pavements which serve the society with minimum amount of defect within the design life of the pavement. The long-term performance of any road depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures.

2.2. Types of Stabilization

Stabilization is the process of blending and mixing materials with a soil to improve the engineering performance of the soil. The process may include blending of soil or mixing of commercially available additives to achieve a desired gradation, plasticity index or swelling potential of the soil and increase durability and strength of the pavement. The tensile strength and stiffness of a subgrade soil can be improved through mechanical stabilization and the use of additives and thereby they are used to reduce the thickness of the overlying pavement layer [3]. As different literatures indicates that soil stabilization can be accomplished by several methods. All these methods fall into two broad categories; these are mechanical and additives or chemical stabilization.

2.2.1. Mechanical stabilization

Mechanical stabilization is a process of improving the quality of soil by mixing different types of soil without the addition of any chemicals. It is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, a central plant, or a borrow area. The blended material is then spread and compacted to required densities by conventional means. It is the most widely used method, where the material is made more stable by adjusting the particle size distribution. Mechanical stabilization is a process of mixing two or more soils with different particle size gradations in order to improve the engineering quality of the soil [13]. It is a process, in which the grading of the soil is improved by the incorporation of another material which affects only the physical properties of the soil (TxDOT February, 2010).

Mechanical stabilization can be achieved by compaction and/or by mixing a different soil with the existing soil.

Compaction

It is the densification of soil by the application of mechanical energy. It is the simplest and the most commonly used method, which increases the performance of a natural material. In stabilization by compaction method, soil density is increased by the application of short-term external mechanical forces to carry the loads that will be applied. It interlocks soil particles and provides a significant effect on soils property, such as strength and stress-strain characteristics, permeability, compression, swelling and water absorption.

Grading and blending

It is a process of mixing two or more soils in order to obtain a material meeting certain specifications. Blending of soil

The effectiveness of stabilization depends upon the ability to obtain uniformity in blending the various materials.

2.2.2. Additives / Chemical Stabilization

Additives are manufactured commercial products that, when added to the soil in the proper quantities, improve some engineering characteristics of the soil such as strength, texture, workability, and plasticity. Chemical stabilization is the transformation of soils index property by adding chemicals. It involves mixing or injecting soil with chemically active compounds such as cement, lime, fly ash, and bitumen. It results a change in both physical and chemical properties of the soil. Under this category, soil stabilization depends mainly on chemical reactions between stabilizer and soil minerals to achieve the desired effect. Proper treatments of problematic soil are extremely important to ensure a long-lasting pavement structure that does not require excessive maintenance.

There are two primary mechanisms by which chemicals alter the soil into a stable subgrade [10]. These are:

I. Increase in particle size by cementation, internal friction among the agglomerates, greater shear strength, reduction in the plasticity index, and reduced shrink/swell potential.
II. Absorption and chemical binding of moisture that will facilitate compaction.

The selection of appropriate stabilizer is based on the plasticity index and particle size distribution of the soil to be stabilized. Based on this appropriate stabilizer can be selected according to the criteria shown in Table 1.1 [6].

Table 2-1 Guide to the type of stabilization likely to be effective

Type of Stabilization	Soil properties					
	More than 25% passing the 0.075 mm sieve			Less than 25% passing the 0.075 mm sieve		
	PI $\leq$ 10	10 < PI $\leq$ 20	PI > 20	PI $\leq$ 6	PI $\leq$ 10	PI > 20
Cement	Yes	Yes	Note 1	Yes	Yes	Yes
Lime	Note 1	Yes	Yes	No	Note 1	Yes
Lime-Pozzolan	Yes	Note 1	No	Yes	Yes	Note 1

Notes 1= the agent will have only a marginal effective

PI = Plasticity Index

Lime

Lime is produced from natural limestone by the decomposition of limestone at elevated temperatures. It is an appropriate stabilizer for most cohesive soils but the level of reactivity depends on the type and amount of clay minerals in the soil. Lime chemically reacts with the clay fraction in the soil to produce desirable changes in the engineering properties of the soil by reducing the Plasticity Index (PI) of the soil and makes less sensitive to moisture changes((IDTBMPR), 2005).

Lime can be used to stabilize the subgrade soils in two different forms like quicklime (calcium oxide - CaO) and hydrated lime (calcium hydroxide - $Ca[OH]_2$).

Quicklime is manufactured by oxidations of limestone at high temperatures, which chemically transforms calcium carbonate into calcium oxide. It is an excellent stabilizer if the subgrade soil is very wet. When it mix with wet soils, immediately takes up to 32% of its own weight of water from the surrounding soil to form hydrated lime and generated heat. The heat came with this reaction will further cause loss of water due to evaporation which in turn results into increased plastic limit of soil. The removal of water and the increase in plastic limit cause a considerable and rapid increase in the strength of the wet soil. Hydrated lime is created when quicklime chemically reacts with water [4]. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementation matrix.

Quicklime has the three major advantages over hydrated lime [4]. This is because of the following reasons:-

- It has higher available free lime content per unit mass,
- It is than hydrated lime and
- It generates heat which accelerate strength gain and large reduction in moisture content according to the reaction equation below
    - $CaO + H_2O = Ca(OH)_2 + \text{Heat (65 KJ/mol)}$

Lime stabilization of clay soils is achieved in the field by shallow/surface stabilization or deep stabilization methods [9].

Shallow stabilization using lime is achieved by mechanical mixing of lime and soil, spreading the mix and then compact it as in the figure shown below.

Figure 2.1 Shallow/surface stabilization

Deep stabilization involves the use of lime columns, lime piles or lime injection methods at large depth into the ground [9]. It is an in situ soil stabilization technology in which a wet or dry binder is injected into the ground and blended with in situ soft soils by mechanical or rotary mixing tool.

Figure 2.2 Deep stabilization

The following are depth of treatment that is advised based on level of traffic [1].

Table 2.2 suggested depth of treatment for highly swelling potential soil types

Heavily trafficked (primary roads)		Lightly trafficked (secondary roads)	
Plasticity index	Depth of treatment (m)	Plasticity index	Depth of treatment (m)
10 - 20	0.60	-	-

20 - 30	0.90	10 - 30	0.60
30 - 40	1.20	30 - 50	0.90
40 - 50	1.50	Over 50	1.20
Over 50	1.80		

Shallow/surface stabilization has the advantage over deep stabilization that it ensures efficient contact between lime and clay mineral particles of the soil.

Lime stabilizer is a widely used means of chemically transforming unstable soils into structurally sound construction foundations. It enhances engineering properties of moderately to highly plastic clays soils including improved strength, improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties, reduced swelling, and resistance to the damaging effects of moisture [3]. Lime stabilized layer forms a water resistant barrier by impeding penetration of gravity water from above and capillary moisture from below. The strength of lime stabilized layer improves the durability of layer under traffic or resistance to the action of water, wind, and freeze-thaw cycles.

When lime combined with water a chemical reaction occurs [14]. This result in:-

- Alteration of particle structure and increase resistance to shrink-swell and moisture susceptibility.
- Binding of particles (when combined with clay) and strength gain.

Plasticity index of highly plastic soils are reduced by the addition of lime to the soil [12]. The amount of lime and soil type is described in the Table below:

Table 2.3 Type of Soil & Lime content

Type of Soil	**Lime content required**
Coarse grained soils	2% to 8%
Plastic Soils	5% to 8%
Fly Ash is added as an admixture	8% to 20%

Therefore, lime is the most preferred method of stabilization for plastic clays, but it becomes ineffective in sulphate rich clays. It facilitates the construction activity in different ways by improving plasticity, workability, shrink-swell potential of expansive soils, and strength of fine-grained soils [8].

Cement

Cement is composed of calcium-silicates and calcium-aluminates that hydrate to form the cementing compounds of calcium-silicate hydrate and calcium-aluminate-hydrate, as well as excess calcium hydroxide when it combines with water. It can be used to treat any soil except highly organic and heavy clay soils [13]. Portland cement can be used either to modify or improve the quality of the soil or to transform the soil into a cemented mass with increased strength and durability, decrease compressibility and swell potential.

Cement stabilization is done by mixing pulverized soil and Portland cement with water and compact the mix to attain a strong material. The material obtained by mixing soil and cement is known as soil-cement. The soil cement becomes a hard and durable structural material as the cement hydrates and develops strength. Cement-stabilized materials are rarely used as a surfacing material because they can become brittle and crack under traffic loads; therefore it is most frequently used for subgrade or road base stabilizer [5].

Portland cement may be successful in stabilizing granular, fine-grained soils and as well as aggregates [2]. It is difficult to mix cement with plastic materials but this problem can be improved by pre-treating the soil with lime to make it more workable. Lime modifies the clay and substantially reduces the plasticity index.

It can also be used effectively as a stabilizer for a wide range of materials; however, the soil having a PI less than 30.

The important factors affecting the soil-cement are nature of soil content, conditions of mixing, compaction, curing and admixtures used [12]. The appropriate amounts of cement needed for different types of soils may be as per the Table below:

Table 2.4 Type of Soil & Cement content

Type of Soil	Cement content required
Soil with high Gravel content	5% to 10%
Sandy Soil	7% to 12%
Silty Soil	12% to 15%
Clayey Soil	12% to 20%

Fly ash

Fly ash is a byproduct of coal fired electric power generation facilities; it has little cementitious properties as compare to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form cementitious compound that contributes to improved strength of soft soil [7].

There is two main classes of fly ashes; class C and class F. Class C fly ash is derived from the burning of lignite or sub-bituminous coal and is often referred to as “high lime” ash because it contains a high percentage of lime. It has high cementing properties because of high content of free CaO (above 30%) resulting in self-cementing characteristics. Class C fly ash is self-reactive or cementitious in the presence of water, in addition to being pozzolanic. Class F fly ashes are produced by burning anthracite and bituminous coal; it has low self-cementing properties due to limited amount of free CaO (below 10%) available for flocculation of clay minerals. This kind of fly ash is not effective as a stabilizing agent by itself, and thus has to be mixed with either lime or lime and cement to be able to stabilize soil [7].

Fly ash can be used effectively to stabilize coarse grained particles with little or no fines. In coarser aggregates, fly ash generally acts as a filler to reduce the void spaces among larger size aggregate particles to float the coarse aggregate particles (TxTI, August 2009). Fly ash has the following benefits [13]. It is used to:

- Lower the water content of soils,
- Reduce shrink-swell potential,
- Increase workability, and
- Increase soil strength and stiffness.

Even if, fly ash has the above benefits it has the following limitations [7]:

- Soil to be stabilized shall have less moisture content; therefore, dewatering may be required.
- Sulfur contents can form expansive minerals in soil-fly ash mixture, which reduces the long term strength and durability.

The reactions prompted by fly ash occur more slowly than cement but more rapidly than lime. When the fly ash mixed with lime, it can be used effectively to stabilize most coarse- and medium-grained soils; however, the PI should not be greater than 25.

Bituminous

Bitumen is a visco-elastic material that occurs in natural asphalt or can be derived from petroleum products. Without increasing the rigidness of the soil, bitumen ensures zero cracking in the soil. If solvent is added in bitumen to make it liquid then, it might have adverse effect on soil properties. Bituminous materials when added to a soil, it imparts both cohesion and reduced water absorption [1]. Generally bitumen of two types is used for stabilization.

I. Cut buck bitumen, is a solution of bitumen with kerosene and/ or diesel.
II. Bitumen emulsion, suspension of bitumen particle in water.

The type of bitumen to be used depends upon the type of soil to be stabilized, method of construction, and weather conditions. In frost areas, the use of tar as a binder should be avoided because of its high temperature susceptibility. Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climate should be selected. As a general rule, the most satisfactory results are obtained when the most viscous liquid asphalt that can be readily mixed into the soil is used. For higher quality mixes in which a central plant is used, viscosity-grade asphalt cements should be used. Much bituminous stabilization is performed in place with the bitumen being applied directly on the soil or soil-aggregate system and the mixing and compaction operations being conducted immediately thereafter. Emulsions are preferred over cutbacks because of energy constraints and pollution control efforts. The specific type and grade of bitumen will depend on the characteristics of the aggregate, the type of construction equipment, and climatic conditions. Soils that can be stabilized effectively with bituminous materials usually have a PI less than 10. Unlike cement and lime, bitumen reacts chemically with the material to be stabilized and it acts as a binding agent, which simply the particles together and prevents ingress of water [1].

Table 1 gives a summary of the mechanisms and applicability of various stabilizing agents and Table 2 illustrates their suitability of stabilizing agents with respect to the plasticity index of the soil [11].

Table 2.5 Mechanisms and applicability of various stabilizing agents

Mechanism	Effects	Suitable Soils
Granular Blending to poorly graded soils, usually coarse into fine (not clayey) soils	Higher compacted density, more uniform mixing, increased shear strength	Gap-graded or gravel deficient (gravel, sand addition), or harsh FCR[a] (loam addition)
Cement Mixing small amounts (cement modification) or larger proportions (cement binding) into soil or FCR[a]	Improve shear strength, reduces moisture sensitivity (modification), greatly increases tensile strength and stiffness (binding)	Most soils, especially granular ones, large amounts of cement needed in clay-rich and poorly graded sands, hence expensive.
Lime Mixing hydrated lime or quick lime in small to moderate amounts into soils	Increases bearing capacity, dries wet soil, improves friability, reduces shrinkage.	Cohesive soils, especially wet, high PI clays.
Bitumen Agglomeration, coating and binding of granular particles	Water proofs, imparts cohesion and stiffness	Granular, non-cohesive soils in hot climates.

[a]FCR = Fine crushed rock road base.

Table 2.6 Suitability of stabilizing agents with respect to the plasticity index of the soil

Plasticity Index	>20	10 – 20	<10	>10	6 – 10	<6
Cement	X	_	_	_	_	_
Lime-fly ash	X	X	_	_	_	_
Lime	_	_	X			
Bituminous			X	X	_	_

X = less suitable

_ = most suitable

2.3. Importance of Subgrade Stabilization

Roads are among the most important public assets in many countries. Roads improvement brings immediate and sometimes dramatic benefits to road users through improved access and mobility to resource and market areas. It also improves safety, comfort, speed and vehicle operating cost. For these benefits to be attained, weak subgrade soil should be stabilized.

The following are the reasons for stabilizing subgrade soils weak subgrade soil [14].

- Reduce shrink/swell of expansive soils or existing materials.
- Reduce moisture susceptibility.
- Increase strength to provide long-term support for the pavement structure.
- Utilize local materials.
- Reduce pavement thickness.
- Provide a working platform for construction of subsequent layers by drying out wet areas and/or temporarily increasing strength properties.

2.4. Subgrade Soil Property of Addis Ababa City

Most of the subgrade material of the city of Addis Ababa is heavy clay and silty clay in nature; and a substantial area of the city subsoil is being occupied by black cotton soil. These soils are not at all useful for any kind of road construction work, otherwise needs treatment; as the soils (black cotton soil) have very low bearing capacity, high water absorbing capacity and a nature of frequent volume change [1].

The plasticity index (PI) of different area of Addis Ababa city subgrade soil is very high ranging from 11.9 to 52.5 and high liquid limit (LL) ranging from 45.5 to 97.5. The nature of the soil is highly expansive and from critical to highly critical. Hence from this report it is possible to conclude that most of the soil of Addis Ababa is very poor to use as subgrade material without having a very thick pavement structure above or treating the subgrade soil. Here are suggested depths of treatment for highly swelling potential soil types in association with the level of traffic [1].

2.5. Factors Affecting the Strength of Stabilized Soil

The presence of organic matters, sulphates, sulphides and carbon dioxide in the stabilized soils may contribute to undesirable strength of stabilized materials [7].

Organic Matter

In many cases, the top layers of most soil constitute large amount of organic matters. Although certain types of organic matter, such as undecomposed vegetation, may not influence stabilization adversely, organic compounds of lower molecular weight, such as nucleic acid and dextrose, act as hydration retarders and reduce strength. Soil organic matters react with hydration product e.g. calcium hydroxide (Ca(OH)2) resulting into low pH value. The resulting low pH value may retard the hydration process and affect the hardening of stabilized soils making it difficult or impossible to compact.

Sulphates

The use of calcium-based stabilizer in sulphate-rich soils causes the stabilized sulphate rich soil in the presence of excess moisture to react and form calcium sulphoaluminate (ettringite) and or thamausite, the product which occupy a greater volume than the combined volume of reactants. However, excess water to one initially present during the time of mixing may be required to dissolve sulphate in order to allow the reaction to proceed.

Sulphides

In many of waste materials and industrial by-product, sulphides in form of iron pyrites (FeS2) may be present. Oxidation of FeS2 will produce sulphuric acid, which in the presence of calcium carbonate, may react to form gypsum (hydrated calcium sulphate) according to the reactions (i) and (ii) below

i. $2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$

ii. $CaCO_3 + H_2SO_4 + H_2O = CaSO_4.2\,H_2O + CO_2$

The hydrated sulphate so formed, and in the presence of excess water may attack the stabilized material in a similar way as sulphate.

Compaction

Stabilized mixture has lower maximum dry density than that of unstabilized soil for a given degree of compaction. In cement stabilized soils, hydration process takes place immediately after cement comes into contact with water. This process involves hardening of soil mix which means that it is necessary to compact the soil mix as soon as possible. Any delay in compaction may result in hardening of stabilized soil mass and therefore extra compaction effort may be required to bring the same effect. That may lead to serious bond breakage and hence loss of strength. Stabilized clay soils are more likely to be affected than other soils due to alteration of plasticity properties of clays. In contrary to cement, delay in compaction for lime-stabilized soils may have some advantages. Lime stabilized soil require mellowing period to allow lime to diffuse through the soil thus producing maximum effects on plasticity. After this period, lime stabilized soil may be remixed and given its final compaction resulting into remarkable strength than otherwise.

Moisture Content

In stabilized soils, enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. Fully hydrated cement takes up about 20% of its own weight of water from the surrounding; on other hand, Quicklime (CaO) takes up about 32% of its own weight of water from the surrounding. Insufficient moisture content will cause binders to compete with soils in order to gain these amounts of moisture. For soils with great soil-water affinity (such as clay, peat and organic soils), the hydration process may be retarded due to insufficient moisture content, which will ultimately affect the final strength.

Temperature

Pozzolanic reaction is sensitive to changes in temperature. In the field, temperature varies continuously throughout the day. Pozzolanic reactions between binders and soil particles will slow down at low temperature and result into lower strength of the stabilized mass. In cold regions, it may be advisable to stabilize the soil during the warm season.

Freeze-Thaw and Dry-Wet Effect

Stabilized soils cannot withstand freeze-thaw cycles. Therefore, in the field, it may be necessary to protect the stabilized soils against frost damage.

Cement stabilized soil are susceptible to frequent dry-wet cycles due to the changes in temperature which may give rise to stresses within a stabilized soil.

3. METHODOLOGY

3.1. Data Collection

In this project stratified random sampling technique had been used to identify AACRA professional staff workers for semi-structured interview. Open and close ended questionnaires are used to collect the necessary data and discussions were made with the professionals about the issue of stabilization in detail. In addition field observation will be employed to collect primary data, more over secondary data will be used.

3.2. Data Analysis

All the primary and secondary data obtain were analyzed on the basis of literature review and theories that had been learned using percentage, charts, tables and figures.

Here are facts or figures found in the study by administrating interviews and questionnaires are explained as follows:

It is clear that the city of the soil is heavy clay, silty clay and black cotton soil in nature. These soils have very low bearing capacity, high water absorbing capacity and exposed to frequent volume change. Because of the above characteristics of the city of the soil AACRA prefers to stabilize the subgrade soils for the following reasons:

- To strengthen a weak soil and restrict the volume change potential of a highly plastic or compressible soil of the city,
- To reduce moisture susceptibility of the city of the soil.

Since 2004 G.C AACRA has began to use additive stabilizer specifically quicklime stabilizer to change the characteristics of the city of the soil by producing long-term permanent strength and stability, particularly with respect to the action of water.

Steps that had been followed by AACRA to stabilize the subgrade soil of the city:-

I. Scarification and Initial Pulverization:

The company first scarifies the existing subgrade soil to the specified depth and width. It is useful to remove non-soil materials, such as stumps, roots, turf, and aggregates. Scarification offers more soil surface contact area for the lime at the time of lime application.

Figure 3.1 Scarification and Initial Pulverization of soil

II. Spreading

The company first arranges the bags of lime along the entire routes of the road using daily laborer just like on the figure shown below. Each bag contains 25kg of quicklime. Then they spread all the lime over the pulverized subgrade soil throughout the road properly using man power. They use two bags of quicklime in order to stabilize one meter square areas of the road.

Figure 3.2 Placement of bags and Spreading of lime

III. Preliminary Mixing and Watering

The company mixes the spread lime with the pulverized subgrade soil using dry mix machine. It is required to distribute the lime throughout the soil and to prepare for the addition of water to initiate the chemical reaction for stabilization. During this process or immediately after, the dry mix water should be sprayed over the dry mix using water shower truck in order to ensure the complete hydration as shown below on the figure.

Figure 3.3 dry mix and water showering

It is clear that Addis Ababa have heavy clay soil because of this it is necessary to mix the lime with clay layer in two stages. The company allows lime-soil mixture should mellow sufficiently to allow the chemical reaction to change (break down) the material, it is typically 1 to 7 days.

The duration of this mellowing period should be based on engineering judgment and is dependent on soil type. For low Plasticity Index soils, or when drying or modification is the goal, mellowing is often not necessary.

IV. Final Mixing and Pulverization

In order to accomplish complete stabilization the company adequately pulverized of the wet clay fraction and thorough distributes the lime throughout the soil. At this time it is essential that all particles have hydrated and have been thoroughly mixed as in the figure shown below.

Figure 3.4 wet mixing

After final mixing, prior to compaction, visually inspect the soil to ensure thorough mixing has been achieved. If there is any doubt in mixing place a sample of these particles in water. If they do not dissolve, they are harmless inert particles. If they do dissolve, they are lime particles, which indicate that additional mixing is needed before final compaction. It is essential that adequate water may be added during final mixing (prior to compaction) to ensure complete hydration and to bring the soil to 3 percent above optimum moisture content of the stabilized material. If the company certain that the pulverization requirement can be met during preliminary mixes the mellowing and final mixing steps may be eliminated.

V. Compaction

The company should begin compaction immediately after final mixing of the wet mix all over the entire road section. They compact the wet soil using heavy pneumatic or vibratory padfoot rollers or a combination of the sheepsfoot and light pneumatic vibratory padfoot rollers or tamping foot rollers. Typically, the final surface compaction is completed using a steel wheel roller as shown in the figure. Finally the stabilized local soil acts as sub-base course and becomes ready for placing base course and coble stone.

Figure 3.5 Shaping and compaction

After the stabilized subgrade has been compacted, it shall be brought to the required lines and grades in accordance with the plans. The completed section shall then be finished by rolling with a pneumatic or other suitable roller.

Here are sample finished roads (Jemo Residential Area Coble Stone Road and Bole Secondary School to Ring Road) constructed by stabilizing the subgrade soil using lime stabilizer and ready for users.

Figure 3.6 Finished surfaces

It is clear that the subgrade soil of Addis Ababa city has higher characteristic in plasticity nature these result in frequent shrink and swell with changes in moisture conditions. This causes a reduction in the density and strength of the subgrade, accelerating pavement deterioration. Therefore, stabilizing of weak sub grade soil of Addis Ababa city has the following two major benefits likes:

I. Quality improvement:- the most common quality improvement achieved through stabilization include better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength.
II. Thickness reduction:- the strength and stiffness of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material.

The following are some of the roads that had been done by using lime stabilizers here in Addis Ababa.

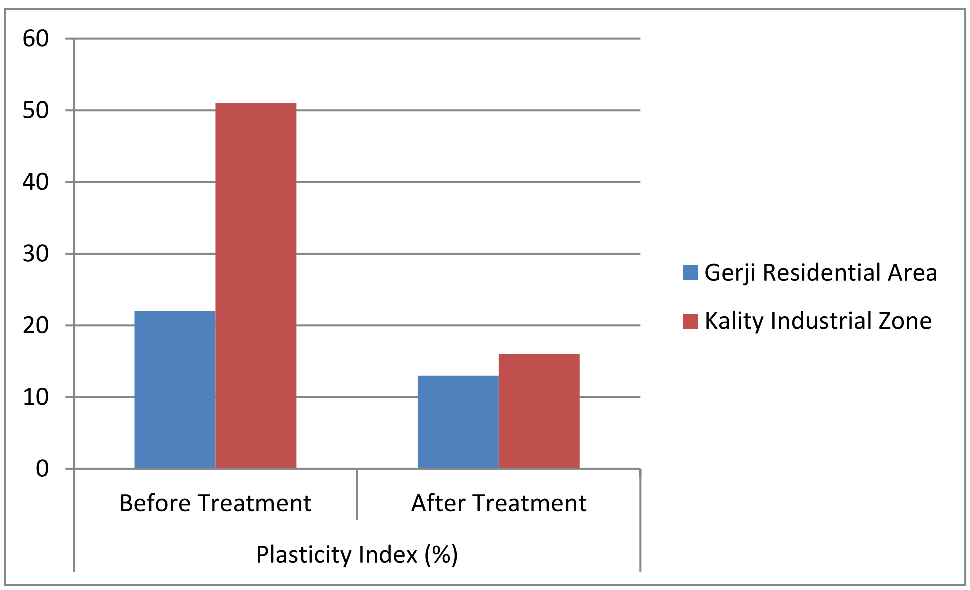
- Bole secondary school to ring road,
- Gabriel Church road,
- Gerji residential area road,
- Civil service road to CMC,
- Jemo residential area, and
- Kality industrial zone

Here is the plasticity index of the two road projects that had been done by using lime stabilizer. The table indicates that the differences in plasticity indexes of the subgrade soil before and after stabilization.

Table 3.1 Plasticity Index of the subgrade soil before and after treatment

Roads Name	Plasticity Index (%)	
	Before Treatment	After Treatment
Gerji Residential Area	22	13
Kality Industrial Zone	51	16

The graph below is used to demonstrate the difference in plasticity index of the soil before and after stabilizing the subgrade soil with lime stabilizer of Gerji Residential Area and Kality Industrial Zone.



Graph 3.1 Plasticity Index before and after treatment

As the graph demonstrate that plasticity index of the soil decreases due to stabilization. Therefore, as the plasticity index of the subgrade soil decreases it:-

- Increases in strength of the soil,
- Decreases swell potential of the soil,
- Decreases pavement thickness and,
- Improves workability.

As the above data indicate that the performance of those pavement structures largely depends on the stability of underlying soil foundation. A minimum acceptable stiffness requirement for pavement subgrade is often specified in the pavement design and construction. Subgrade soil stabilization is used to improve the stability when questionable soils are encountered. The main advantage of subgrade stabilization compared to “remove and replace” option is that it provides a more uniform support for the pavement structure throughout the project.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

Most of the subgrade material of the city of Addis Ababa is heavy clay and silty clay in nature; and a substantial area of the city subsoil is being occupied by black cotton soil. Black cotton and clay soils have higher plasticity index, swelling and shrinkage characteristics by these they have lower load bearing capacity and stiffness. These soils are not at all useful for any kind of road construction work, otherwise needs treatment. The application of stabilizers in a subgrade soil will result in increase the load bearing capacity or strength, stiffness, improve durability, reduce plasticity of the soil, reduce the swelling potential of the soil, facilitate compaction process, reduce the overlying pavement thickness and enhance long term structural stability. Lime is an appropriate stabilizer for most cohesive soils but the level of reactivity depends on the type and amount of clay minerals in the soil. Lime chemically reacts with the clay fraction in the soil to produce desirable changes in the engineering properties of the soil. AACRA uses lime as subgrade stabilizer for lot of roads, they had poor documentation practice.

4.2. Recommendations

- The company should have to deliver a mask to the daily laborer or use machine to distribute the lime.

- It becomes a base for further studies.
- AACRA has poor documentation management system. Even they did not have files for most the stabilized roads.

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Appendix

Questioner for partial fulfillment of M. Eng. program in Road and Transport Engineering

1. What type of stabilization do you practice?
    A. Chemical stabilization
    B. Mechanical stabilization
    C. Others
2. If it is chemical stabilization, what kind of chemical do you use?

    ____

3. Why?

    ____
    ____
    ____
    ____
    ____

4. What are the benefits of this stabilizer?

    ____
    ____

____

____

____

5. How can you select this stabilizer?

____

____

6. When did AACRA start lime stabilizer practice? Specify the year.
7. Does stabilization reduce the shrinkage and swell potential of a soil?
   A. Yes
   B. No
8. If the answer for the above question is yes, what is the swell potential of the soil before and after stabilization?

   Gerji road_____________ and ________________

   Jemo road _____________ and ________________

   Kality industrial zone _______________ and _______________
9. Does lime stabilizer minimize the thickness of the overlying layers?
   A. Yes
   B. No
10. Does lime stabilizer improve the workability of expansive soils?
    A. Yes
    B. No
11. Does lime stabilizer increase the plastic limit of expansive soils?
    C. Yes
    D. No
12. Which type of lime do you use for stabilizing subgrade soil?
    A. Quicklime
    B. Hydrated lime
13. Why?

____

____

____

14. If you use quicklime, how many bags do you use for a meter square area of soil?

____

15. What is the roads' traffic classification? Heavy or light?

    Gerji road ________________________________

    Jemo road _________________________________

    Kality industrial zone ________________________________

16. What are the plasticity indexes of the soil and depth of treatment in meter?

    Gerji road ________________ and ________________

    Jemo road _________________ and ________________

    Kality industrial zone ________________ and ________________

17. What are the plasticity indexes of the soil after treatment?

    Gerji road ________________

    Jemo road _________________

    Kality industrial zone ________________

APPROVAL SHEET

GRADUATE PROGRAM

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

Submitted by:

_____________________	_________________	____________
Name of the student	Signature	Date

Approved by:

1. _______________	________________	______________
Name of Major Advisor	Signature	Date
2._________________	________________	______________
Name of Co-Advisor	Signature	Date
3.___________________	_______________	_____________

Name of Chairman, DGC[1] Signature Date

4.______________________ ________________ ______________

Name of Dean, Graduate Program Signature Date

5.___________________ ________________ ______________

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